Evaluation of Technical Feasibility and Optimum Mix Parameters for Recycled Asphalt Pavements in Sri Lanka

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***Abstract*—Recycled or reclaimed asphalt pavement (RAP) utilization has increased in the pavement sector as a result of the depleting availability of virgin materials, rising production costs, and a lack of landfill space to dispose of old materials in many countries. Here, when a road needs to be paved, the old pavement is milled from the road and then subsequently crushed, screened, and reincorporated into a fresh asphalt mix. In Sri Lanka, there has been rapid improvement in the road engineering sector over the past few years. However, the use of recycled asphalt pavements has not been seen either in repaving or constructing new roads in Sri Lanka. This research was initiated to assess the suitability of RAP materials in Sri Lanka by Marshall Mix Design and to evaluate their technical feasibility. In this study, different percentages of RAP were mixed with virgin binder and virgin aggregates to perform the Marshall Mix Design, and the results were compared with the performance criteria of a control mix specimen (0% RAP). The existing RAP binder content was determined using the centrifuge extraction method. The results of Marshall stability, Marshall flow, Air voids (V_a), and Voids in mineral aggregates (VMA) were meticulously analyzed for each percentage of RAP mix specimen to determine the optimum mix parameters for RAP.**

***Keywords*—Recycled asphalt pavement (RAP), marshall mix design, road engineering, optimum mix parameters**

I. INTRODUCTION

Hot Mix Asphalt (HMA) has been extensively used as a pavement mix in road construction in Sri Lanka, as most of the urban and considerable portions of the rural road networks are bituminous pavements. Typically, for HMA production, aggregates are obtained through rock blasting, and these natural resources are depleting, resulting in increased costs alongside the rising production costs of virgin asphalt binder. Consequently, there is an urgent need to identify suitable and cost-effective materials for road paving in Sri Lanka. Conventionally, in Sri Lanka, when a road needs to be repaved, a new HMA mixture is applied over the degraded surface or the deteriorated surface is milled out and disposed of without further use. In the RAP method, the damaged surface is milled out, then crushed, screened, and reincorporated into a fresh asphalt mix, which is subsequently applied as a recycled asphalt mixture.

To date, studies have been conducted on the use of RAP in HMA mixtures in various countries. Because of its unique qualities, RAP serves as a practical and cost-effective substitute for virgin aggregates, consequently reducing the demand for new virgin aggregates. Additionally, the utilization of RAP leads to decreased reliance on expensive new asphalt binders in asphalt paving mixtures, further enhancing its benefits [1]. It was found that the aged asphalt binder in RAP coats the RAP aggregate particles in a stiffer layer as opposed to a mixture with 100% virgin asphalt, and the addition of RAP to HMA mixtures has the advantageous result of creating a good layered structure to improve the performance of the pavement [2]. Some previous research findings have suggested that asphalt mixtures incorporating RAP can exhibit equivalent or even superior structural performance compared to virgin asphalt concrete, provided they are designed appropriately with the right recycled asphalt concrete design and a suitable RAP percentage [3].

To avoid detrimental effects on the mix properties, most road authorities allow no more than 30% of RAP to be used in hot mix asphalt (wearing course). This is mainly because of RAP's general stiffness, largely resulting from oxidative hardening and other aging processes it endures over its period of exposure to the environment during its service life [4].

A method for determining the necessary mix design properties (such as stability, flow, and air void content) for the Marshall mix design method is provided in the Asphalt Institute's manual on mix design methods for asphalt concrete [5]. After conducting mix design testing for the asphalt mixes including 6 aggregate combinations with RAP levels of 0% (control), 5%, 10%, 15%, 20%, and 25% by standard procedures to meet the relevant mix design criteria, the optimum mix parameters for RAP mixtures will be established. The objective of this study is to recommend guidelines and best practices for the incorporation of RAP in hot mix asphalt to achieve sustainable and high-performance road pavements in Sri Lanka by investigating the impact of varying RAP percentages on the volumetric properties, stability, and flow characteristics of hot mix asphalt.

II. METHODOLGY

For this study, the Marshall method was used as it is the widely accepted method for designing asphalt mixes. This enables to stress a complete sample rather than just a portion of it for stability and flow. Fig. 1. Shows the experimental methodology used in this study.

A. *RAP Materials and Virgin Aggregates*

The source of the RAP material was a road rehabilitation project near Trincomalee, where the upper layer of the existing pavement was removed. Then the collected RAP materials were hammered and crushed. Using the centrifuge extraction method, the existing bitumen percentage of RAP materials was determined as per AASHTO T164-06 [6]. Virgin aggregates were obtained from a crusher plant located near Trincomalee and Sieve Analysis was performed for both virgin and RAP aggregates according to AASHTO T27-99 [7] to grade the aggregates for Wearing Course Type 2 as given in the ICTAD (Institute for Construction Training and Development) specifications [8]. To determine the engineering properties of RAP aggregates, Aggregate Impact Value (AIV), Los Angeles Abrasion Value (LAAV), Flakiness Index test, Bulk Specific Gravity test (G_{sb}) and Water Absorption test were conducted in accordance with BS 812-112: 1990(1990) [9], AASHTO T96-02(2002) [10], BS 812: part 105.1:1989(1990) [11] and AASHTO T85–91(2000) [12] respectively. These obtained properties were compared with the virgin aggregates to evaluate whether they are in conformity with the specified range of fresh aggregates.

B. *Virgin Binder*

Bitumen penetration grade 60/70 was selected for this research because it is the grade of bitumen commonly used in road construction in Sri Lanka.

C. *Marshall Testing*

After collecting virgin aggregates, RAP materials, and bitumen binder, the Marshall test was conducted to a series of trial aggregate-asphalt binder mixes. The bitumen content was varied in 0.5% increments to determine the optimum binder content (OBC). The range of bitumen content percentages tested included 4%, 4.5%, 5%, 5.5%, and 6%, in accordance with ICTAD specifications. A total of 15 specimens were prepared, with 3 samples allocated for each blend. Then the OBC was determined by evaluating the Marshall stability, Marshall flow, and volumetric properties of each blend.

After determining the OBC value, that value was used to make a controlled sample (0% RAP) and 5 other RAP samples as well. For this, 3 samples were prepared for each RAP content. When preparing the RAP specimens, the existing bitumen content was disregarded for the 5%, 10%, and 15% mixes. For the 20% and 25% RAP mixes, half of the existing binder content was considered [13], and virgin binder was added to reach the required amount to achieve OBC. These RAP samples were with 5%, 10%, 15%, 20%, and 25% of RAP. The obtained results for Marshall stability, Marshall flow, and volumetric properties of the control sample and RAP samples were compared to the values given in the ICTAD specifications for high-traffic, flexible pavements.

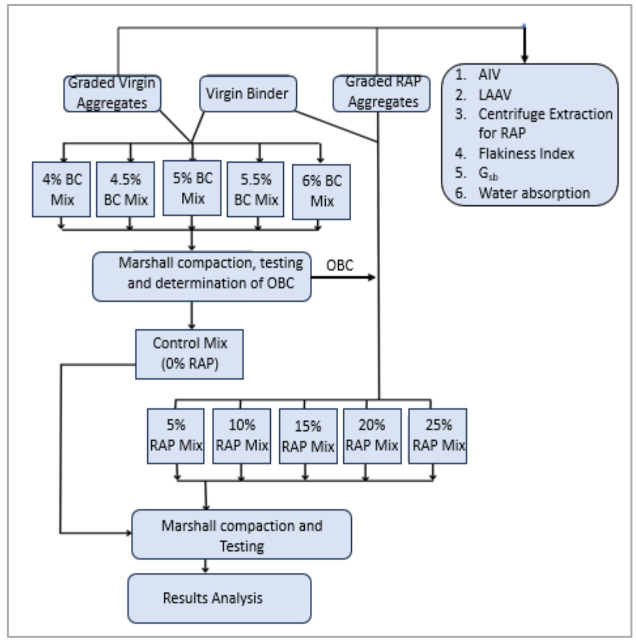

Fig. 1. Experimental methodology flow chart

TABLE I. PHYSICAL PROPERTIES OF VIRGIN AND RAP AGGREGATES

Aggregate Properties	Virgin Aggregates	RAP Aggregates	ICTAD Requirements
AIV (%)	14.39	6.2	<30
LAAV (%)	39.1	38.5	<40
Flakiness Index Value (%)	21.22	10.12	<35
G_{sb}	2.707	2.361	<2.75
Water Absorption (%)	0.37	0.30	<2.0

III. RESULTS AND DISCUSSION

A. *Physical Properties of Virgin and RAP Aggregates*

The results of AIV, LAAV, Flakiness Index test, Water absorption, and Bulk Specific Gravity for virgin aggregates and RAP aggregates are shown in Table I.

The toughness of the specimens was measured by the AIV test and the obtained values for both virgin and RAP aggregates were within the ICTAD acceptable range. The lower value shown by the RAP sample may be due to the presence of an aged binder layer which tends to develop a more resilient and cohesive matrix over time. Abrasion values were also within the ICTAD required range for both specimen types. The higher value shown by the RAP sample may also be due to the presence of an aged binder layer which causes brittleness, and ultimately leads to increased abrasion and wear of the aggregate particles. Both RAP and virgin aggregates displayed an acceptable flakiness index.

G_{sb} value for RAP showed a lower value than virgin aggregates. This may be because of the brittle and less cohesive nature of the aged binder which could create additional voids within the RAP aggregates. The water absorption of RAP aggregates was also lower than that of virgin aggregates. This may be attributed to the coating of RAP aggregates with asphalt binder, which could aid in covering the existing voids of the aggregate and reducing the water absorption.

B. Existing Bitumen Percentage of RAP

From the mass difference of dried aggregate sample before the test and aggregate sample after the centrifuge extraction, existing bitumen percentage of RAP was calculated. The resulting value was 4.19%.

C. Optimum Binder Content (OBC)

The OBC for the control and RAP mixes were determined by the Asphalt Institute procedure from the individual plots of, air voids, unit weight, stability, and flow versus percent binder content. Corresponding binder content values for achieving 4% of air voids, maximum unit weight, and maximum stability were considered. The average value was taken as the OBC, and the target OBC was verified to ensure that the VMA and flow requirements were met. The obtained binder content value was 4.8%.

D. Marshall Properties Analysis

Table II shows the results from the Marshall tests on control and RAP specimens with the ICTAD requirements. It was revealed that all the values obtained for RAP samples lie between the ICTAD specified range. Fig. 2, Fig. 3, Fig. 4, and Fig.5 are comparison diagrams of mixtures before and after the addition of RAP based on Marshall stability, Marshall flow, V_a, and VMA respectively.

TABLE II. MARSHALL AND VOLUMETRIC PROPERTIES FOR DIFFERENT RAP CONTENTS

Marshall Property	**0% RAP**	**5% RAP**	**10% RAP**	**15% RAP**	**20% RAP**	**25% RAP**	**ICTAD Requirements**
Stability (kN)	12.73	12.73	12.75	14.89	13.82	13.28	≥ 8
Flow (0.25mm)	9.6	9.2	11.6	11.6	12.4	12.8	8 - 16
V_a (%)	3.98	3.95	3.9	3.88	3.73	3.59	3 - 5
VMA (%)	14.94	15.39	15.84	16.31	16.66	17.03	≥ 13

According to Fig. 2, the stability value increases up to 15% RAP and then tends to decrease with the increasing RAP content. It was revealed that the addition of RAP increased the stability of the control mix and the highest increase was at the 15% RAP, which was 16.96%.

Based on Fig. 3, it was found that the flow value tends to increase with the increasing RAP content. 25% RAP specimen shows the highest flow value and increasing flow value will make the specimens more plastic and easier to deform. The reason for the increasing flow value may be due to the increasing aged binder content which shows lower cohesive properties than the virgin binder. This can make the mixtures with high RAP percentages more prone to deformation or flow.

Fig. 4 showed that the V_a value tends to decrease with the increasing RAP content. Increasing RAP content decreases the virgin binder content which could lead to more compacted mixtures with fewer air voids.

Fig. 5 revealed that VMA value tends to increase with the increasing RAP content. This could be because the aged binder may not coat the aggregates as effectively as virgin binder. This could create void spaces within the mineral aggregates.

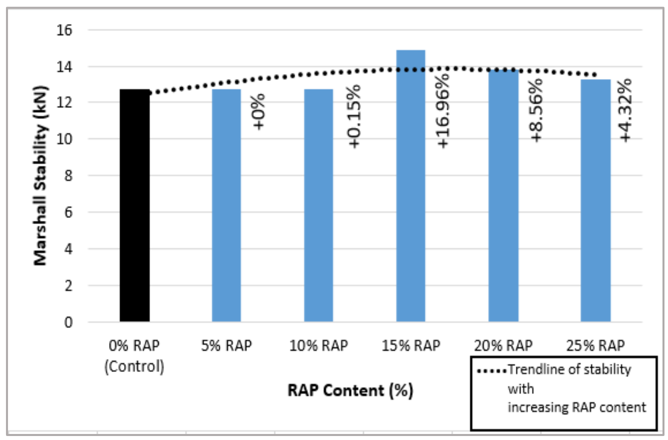

Fig. 2. Variation of Marshall stability with RAP content

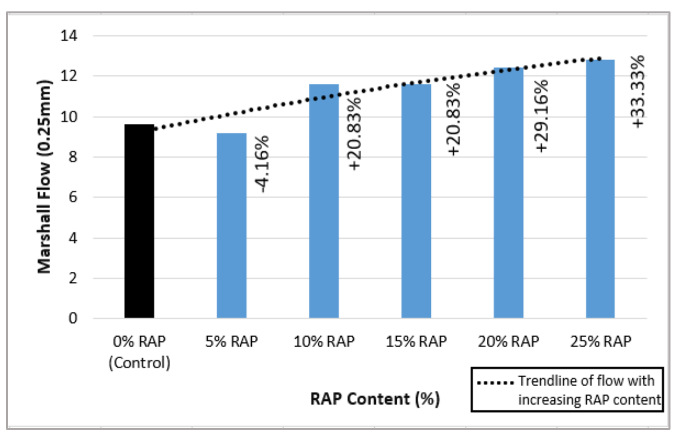

Fig. 3. Variation of Marshall flow with RAP content

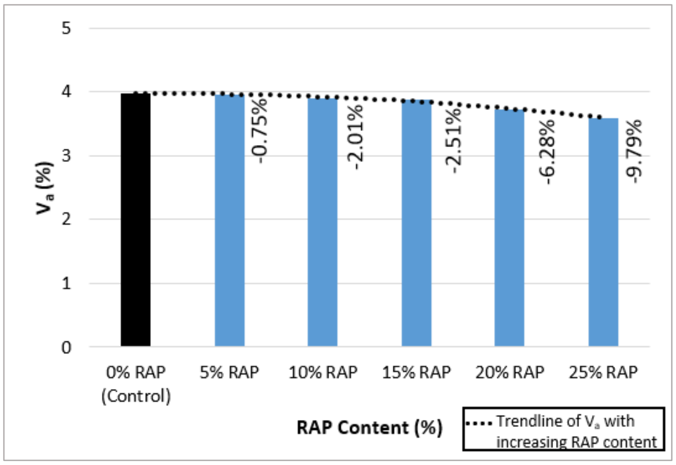

Fig. 4. Variation of V_a with RAP content

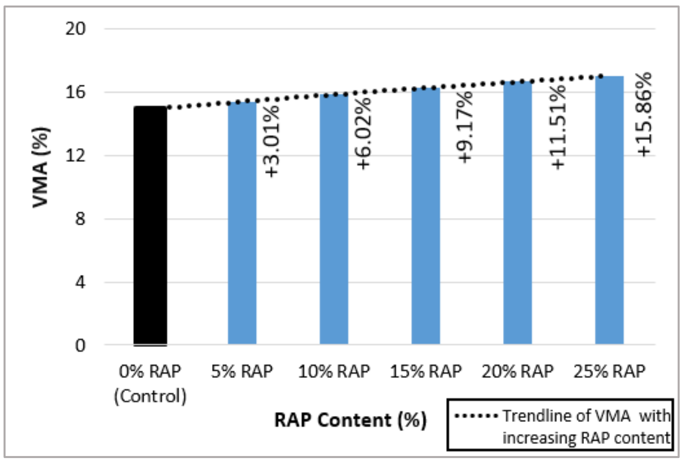

Fig. 5. Variation of VMA with RAP content

IV. Conclusions

The following can be concluded from this study:

1. Laboratory investigation of the physical properties of aggregates showed that both RAP and virgin aggregates used for this study complied with the requirements of ICTAD.
2. HMA mixtures including RAP can show higher Marshall Stability values than conventional (0% RAP) HMA mixtures.
3. The addition of RAP increases the susceptibility of HMA mixtures to deformation but remains within the specified ICTAD range.
4. Increasing RAP percentage affects the volumetric properties of HMA mixtures by decreasing V_a and increasing VMA values, possibly due to the presence of aged binder. However, all values remain within the specified ICTAD range.

Most importantly, all Marshall and volumetric properties even at the highest RAP content of 25%, fall within the specified ICTAD requirements. However, it can be concluded that beyond 15% RAP, factors such as inadequate virgin binder content and increased amount of aged asphalt binder can start to outweigh the benefits of RAP incorporation. Based on the technical analysis of Marshall properties, a 15% RAP percentage can be used as an optimal RAP content for incorporation into HMA mixtures in Sri Lanka, since it offers a balanced approach by providing a substantial high amount of stability value, moderate flow value and with the slight reduction of air voids it provides an improved density condition.

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